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Project Title:

Reducing Insecticide Use on Celery Through Low-input Pest Management Strategies

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Executive Summary:

We proposed to implement a low-pesticide-input integrated pest management (low-input IPM) system for celery, and compare its performance with conventional high-pesticide-input management systems. This project directly relates to the Department of Pesticide Regulation priority areas involving (1) testing and evaluating experimental IPM systems of major arthropod pests that are a problem in multiple commodities, and (2) management projects that address environmental quality. Because of low damage thresholds, celery is among the most intensively managed vegetable crops and therefore is a model system for development of low-input IPM programs. Successful development of low-input IPM programs in such an intensively managed crop will facilitate the acceptance of similar programs for other vegetable crops.

The first year of this two year project was completed on schedule, as described in the original proposal. This study has been conducted on a commercial scale in collaboration with a celery producer, in Ventura County. The celery was transplanted August 27, 1997, and was harvested on December 26 and 27, 1997.

The low-input IPM program relied on biological control agents, and environmentally-safe biorational insecticides applied only "as needed" in a rotational strategy to delay pesticide resistance. The need for insecticide applications in the low-input IPM program was determined from weekly insect samples. Overall, the low-input insect management program used one-third fewer insecticides than the grower standard. Although the low-input program used significantly fewer insecticides than the grower standard, there was no significant difference in yield or net profit between the treatments. The grower standard practice had an average yield of 2,748 marketable cartons per hectare (1,112 cartons per acre). The low-input IPM program yielded an average of 2,751 marketable cartons per hectare (1,113 cartons per acre). Based on Free on Board (F.O.B.) market prices at the time of harvest. The net profit for the grower standard was $8,130 per hectare ($3,290 per acre), and the net profit for the low-input IPM program was $8,052 per hectare ($3,258 per acre).

In addition to the favorable economic results, the low-input IPM program has benefits for the environment. The insecticides selected for use in the low-input IPM program are formulated without volatile solvents. Therefore this low-input approach would not contribute substantially to air pollution from volatile emissions.

In the first year of this project we have demonstrated that further reductions in pesticide use can be made in the production of high value, low damage threshold vegetable crops such as celery. This reduction in pesticide use can be made without sacrificing yield, quality or net profit. The progressive insect pest management policy of the grower made this validation test of the low-input IPM program conservative. Hence, many growers could show

greater economic benefits from adoption of such low-input programs. Additional progress in successfully reducing pesticide use could be made by developing similar low-input programs for the control of fungal pathogens.

Results and Discussion:

We proposed to implement a low-pesticide-input integrated pest management (low-input IPM) system for celery, and compare its performance with conventional high-pesticide-input management systems. This proposal directly relates to the Department of Pesticide Regulation priority areas involving (1) testing and evaluating experimental IPM systems of major arthropod pests that are a problem in multiple commodities, and (2) management projects that address environmental quality. Because of low damage thresholds, celery is among the most intensively managed vegetable crops and therefore is a model system for development of low-input IPM programs. Successful development of low-input IPM programs in such an intensively managed crop will facilitate the acceptance of similar programs for other vegetable crops.

The first year of this two year project was completed on schedule, as described in the original proposal (Table 1). This study has been conducted on a commercial scale in collaboration with a celery producer, in Ventura County. The field site is the Gene Jackson Farms' Maxwell Ranch, Ventura, California.

The personnel for the project were identified at the initiation of the project and made aware of the methodology and scope of the project. Mr. Gerry Benson was the field representative and pest control advisor for Gene Jackson Farms. He has been responsible for supervising the "conventional grower practice" treatments. He contracted with a commercial pesticide application company that conducted all pesticide applications, under our supervision. Dr. Phil Phillips, University of California Cooperative Extension, Ventura County, has collaborated in collecting data on meteorological and microenvironmental conditions at the field site.

Because of California state law mandating a celery free period, fields in Ventura County could not be planted until August 1997. This fact was taken into account in our schedule, and transplanting of celery into the experimental plots began August 29, 1997. Plantings consisted of field-grown 'G20' celery transplants.

Experimental plots for the first year were staked out and arranged in a randomized complete block design. The two insecticide treatments were the low-input pest management (low-input IPM) treatment and the grower's standard treatment. In addition to the originally proposed insect pest management program, we included a program to monitor development of *Septoria* late blight. In this aspect there were two treatments. One treatment was the grower's standard fungicide application program, and the second was a treatment where fungicides for *Septoria* control were applied in response to disease severity forecasts. The insect management treatments and *Septoria* management treatments were cross classified resulting in a randomized block design with three blocks and four replicates per block. Each replicate was 0.4 ha (1acre) in size. No untreated control was incorporated into the design because the grower could not be expected to tolerate the probable economic loss.

Determination of the need for insecticide applications in the low-input IPM treatment was based on insect counts. Because of the constant sprinkler irrigation of celery following transplantation, arthropod sampling was not possible until September 10, 1997. Evaluations of lepidopteran populations, based on counts of 20 plants per replicate, were conducted on a weekly basis since that date. For lepidopterous pests, treatments in the low-input IPM were applied when average densities exceeded 1 larva per 10 plants. *Liriomyza* spp. populations were also evaluated by weekly counts of leafminer larvae in foliage of 20 plants per replicate, and later by counting larvae and puparia collected in 4 (10.2 by 20.4 cm) trays per replicate. *Liriomyza* spp. populations exceeding 10 per replicate (early season) or per tray (late season), in the low-input IPM plots, were considered above threshold.

The low-input IPM program relied on biological control agents, and environmentally-safe biorational insecticides applied only "as needed" in a rotational strategy to delay pesticide resistance. Resistance management is a paramount concern, given the broad resistance to synthetic insecticides of two key celery pests, *Spodoptera exigua* and *Liriomyza trifolii*, and the increasing pest status of *L. huidobrensis*.

Insect pest pressure was high enough to warrant treatment in both the grower standard and low-input IPM plots (Table 2). The insecticides used and the number of respective applications in the chemical standard treatment were at the discretion of the grower. The grower standard plots received seven separate applications of insecticides whereas the low-input IPM treatments received six separate insecticide applications.

In the low-input IPM treatment, we rotated among commercial formulations of *Bacillus thuringiensis* (up to 1.67 kg [AI]/ha, Xentari, Abbott, Chicago, IL, or Crymax, Ecogen, Langhorne, PA), tebufenozide (RH-5992 [Confirm], Rohm & Haas, Philadelphia, PA, at 1.12 kg[AI]/ha) and spinosad (0.06 kg [AI]/ha, Success, Dow Elanco, Indianapolis, IN) to control lepidopteran populations above the threshold values. The insecticides used to control lepidopterous pests in the low-input IPM program were selected for their minimal impact on *Liriomyza* spp. parasitoids. On one occasion (October 8, 1997) *Liriomyza* populations exceeded threshold densities in the low-input plots. Because of the increasing presence of the more destructive *L. huidobrensis*, a conservative decision was made to treat these high leafminer populations with a single application of cyromazine 0.05 kg [AI]/ha (Trigard, Novartis, Greensboro, NC). The grower standard used three insecticide applications to control leafminers.

On October 28, 1997, one application of oxamyl (1.07 kg [AI]/ha, Vydate L, DuPont, Wilmington, DE) was made via side dressing the beds, to control an aphid infestation. A corporate decision was made to apply thiodicarb (0.67 kg/ha, Larvin 3.2, Rhône-Poulenc, Research Triangle Park, NC) on November

12, 1997. Because of this late date in the growing season, it was necessary to apply the thiodicarb through the sprinkler system (i.e., chemigation) to all plots. The commercial nature of the project necessitated that the grower having ultimate discretion in applying insecticides to the field.

Fields were harvested on December 26 and 27, 1997 by commercial harvest crews employed by Gene Jackson Farms. Harvest crews were unaware of treatment differences among plots. The numbers of cartons in each size class harvested from each replicate were recorded.

Objectives:

Objective 1: To generate a partial budget economic analysis comparing the monetary returns (gross costs, net gain/profit) accruing from the use of current conventional insecticide practices and the low-input program on a standard commercial variety of celery.

For the economic analyses, all non-pesticide costs were derived from industrywide standards (Table 3, see Trumble, J. T. et al. 1997, J. Econ. Entomol. 90: 139-146). Harvest and marketing costs were also determined in this manner. All pesticide costs (materials and labor) were derived from costs supplied by commercial application firms for treating large acreages of celery. Market prices used for analyses are the free on board (F.O.B.) shipping point prices for the South District of California on the date nearest harvest (USDA Market News Service).

There were no statistically significant differences in the yield (Figure 1) or net profit per hectare for the two insect management programs (Figure 2). The grower standard practice had an average yield of 2,748 marketable cartons per hectare (1,112 cartons per acre). The low-input IPM program yielded an average of 2,751 marketable cartons per hectare (1,113 cartons per acre). Based on Free on Board (F.O.B.) market prices at the time of harvest. The net profit for the grower standard was $8,130 per hectare ($3,290 per acre), and the net profit for the low-input IPM program was $8,052 per hectare ($3,258 per acre).

However, the low-input program had one fewer insecticide applications (six versus seven) than the grower standard program. Furthermore because of the system, one application for the grower standard was necessarily applied to the low-input treatment plots, and one application for aphid control was outside of the scope of the low-input program. Overall the low-input program used one third fewer insecticides than the grower standard program with no significant impact on net profit. This reduction in insecticide use resulted in a savings of $208.70 per hectare in insecticide costs.

In addition to the reduction in insecticides applied, use of the Tomcast model for forecasting development of *Septoria* late blight resulted in one less fungicide application compared with the grower standard. Further significant reductions in fungicide use would be possible if forecasting models for other fungal pathogens (e.g., *Rhizoctinia*) were available.

Objective 2: To estimate the potential for air pollution from solvent emissions from insecticide applications.

The insecticides selected for use in the low-input IPM program are formulated without volatile solvents. Therefore this approach would not contribute substantially to air pollution. In fact the progressive management program used by the grower included only one insecticide with a volatile component, thiodicarb. The grower applied thiodicarb three times during the course of the growing season. One of these applications was a late season chemigation applied across all plots. Therefore, the grower standard program would produced approximately 2700 ml/ha of solvents. Excluding the chemigation, the low-input IPM program would have resulted in no solvents being released. Including that chemigation, the low-input IPM program would have released approximately 1500 ml/ha of solvents. Given that the average solvent emissions from many current vegetable pest management programs can reach 12 liters per hectare per crop, the potential benefits of the low-input IPM program which eliminates emissions could be substantial.

Objective 3: To determine environmental health of agroecosystems subjected to the conventional and low-input programs by determining the diversity and abundance of selected arthropods present.

Three times during the growing season, we estimated the abundance and diversity of selected arthropods in the experimental plots. The general abundance and diversity sampling were performed following inspections for lepidopteran and leafminer pests. Pitfall traps were examined for soil-surface dwelling predaceous insects and arachnids. Specimens collected during these searches were preserved for later identification.

The lack of sufficient numbers of specimens precluded a meaningful statistical analysis of the diversity and abundance data. However, similar numbers and types of predaceous arthropods (e.g., Lyniphiidae, Staphylinidae) were found in all plots.

Objective 4: To communicate information to the celery industry and the local communities via field days at the research sites, and via the California Celery Research Advisory Board and presentations sponsored by the University of California Extension Service.

Results for the first year of this two year study have been presented at meetings and in publications accessible to the vegetable producer industry. Presentations have been made at the "Celery IPM Innovator Workshop" that was held on November 6, 1997, in Ventura, and was cosponsored by the California Department of Pesticide Regulation, the California Celery Research Advisory Board and the University of California. The results have also been presented to the California Celery Research Advisory Board. Articles describing the project have been published in *Vegetable*, November/December 1997, pp. 4-7, and *Agribusiness Fieldman*, November/December 1997, pp.1-4. In addition, manuscripts for submission to Agriculture Ecosystems & Environment and California Agriculture are in preparation.

Conclusions:

The utility of the results from the proposed low-input IPM program merits particular mention. This project specifically addresses grower concerns about the perceived risks in the use of a low-input system. The low-input IPM program will provide detailed data on the economic returns from the proposed strategies using the types of analyses the growers employ. Creation of partial budgets using accurate economic information provided by growers (Trumble et al., 1997) can generate persuasive data on net profits resulting from specific control strategies. Thus, if successful, implementation could occur rapidly once the barrier of 'perceived risks' is eliminated.

While progress in reducing pesticide use has been made in recent years, the implementation of such low-input integrated pest management strategies is not likely to proceed solely on the basis of environmental benefits. Similarly, coercive legislated regulations are not likely to enhance the wide scale adoption of low-input IPM strategies. The demonstration of clear economic benefits of such low-input IPM strategies to producers is the most effective means to accelerate the adoption of such programs and create a demand for development of additional low-input IPM programs for other agroecosystems.

Therefore, we selected celery as a model agroecosystem for the development of a low-input IPM program. Because of low damage thresholds, celery is one of the most intensively managed vegetable crops in California. Successful development of low-input IPM in such an intensively managed, high value crop system is expected to facilitate the acceptance of similar low-input IPM programs for other vegetable crops nationally.

Because of concerns about perceived risks, a strong need exists for new approaches to insect pest management in celery that allow producers to achieve equivalent economic returns to current conventional practices without 1) resorting to Class I pesticides (highly toxic to mammals, fish and/or birds) or, 2) allowing *Liriomyza* spp. damage levels to impact linear furanocoumarin levels. Therefore, accurate economic information on the benefits of proposed IPM strategies is needed by producers on the benefit of use of alternative programs relying on pesticides with low mammalian toxicity, which have broad legislative and public acceptance.

In the first year of this project we have demonstrated that such a low-input IPM program is economically viable. Our results indicate that through adequate sampling to determine the appropriate need for insecticide applications, further significant reductions in insecticide use can be made by the vegetable industry. Additional progress in successfully reducing pesticide use could be made by developing similar low-input programs for the control of fungal pathogens. We would encourage the development of monitoring programs similar to the one for *Septoria* late blight for other fungal pathogens. Refinement of such low-input programs for insect and fungal pests will produce successful, comprehensive intelligent plant management programs.

Table 1. Schedule for Achieving Results

Year 1 -- 1997-1998:

July:	Prepare land for planting (completed)
August:	Plant celery (transplants obtained from Duda California seed beds, Santa Maria, CA) (completed) Begin experiments and monitoring and field days. (completed)
Sept. - Nov.:	Continue experiments and monitoring and field days. (completed)
December:	Harvest and collection of final economic data. (completed)
Jan. - Feb.:	Linear furanocoumarin analyses and complete arthropod identifications. (in progress)
March:	Submit final report for year 1.

Table 2. Insecticide applications for the grower standard and low-input IPM treatments on commercial celery fields.

	Insecticide Applications	
Date	Standard	Low-Input
9-13-97	Larvin [a] Xentari [a] Trigard [b]	Xentari
9-22-97	Larvin [a] Agrimek [b]	RH-5992 [a] (Confirm)
9-30-97	Xentari [a]	(none)
10-8-97	Success [ab]	RH-5992 [a] (Confirm) Trigard [b]
10-28-97	Success [ab] Vydate[c]	Vydate[c]
11-12-97 [d]	Larvin [a] Crymax [a]	Larvin [a] Crymax [a]
11-20-97 [e]	Success [ab]	Success [ab]

[a] Insecticide targets lepidopteran pests

[b] Insecticide targets leafminer pests

[c] Applied across all plots for aphid pests

[d] Chemigated across all plots

[e] Aerial application across all plots

Table 3. Cost estimates for production and harvest of celery

Costs per hectare	Grower Number 1	2	3	4	5	6	7	8	Value[1]
Fixed costs									
Water	148.26	642.46	123.55	281.69	494.20	210.04	1235.50	370.65	370.65
Seed	32.12	-	25.95	-	-	49.42	49.42	49.42	49.42
Transplants	2883.67	2125.06	2479.52	1976.80	2070.70	1976.80	2601.96	2335.10	2223.90
Planting	639.99	457.14	644.61	420.07	667.17	741.30	679.53	506.56	494.20
Scouting	54.36	-	-	-	-	44.48	49.42	51.89	49.42
Other costs[2]	756.13	4942.00	5059.74	3177.71	6651.93	4351.43	370.65	5436.20	4942.00
Variable Costs (per carton)									
Harvest costs	4.10	3.60	3.75	-	3.60	4.22	1.80	3.45	3.70
Sales costs	inc.	0.25	0.41	-	0.50	inc.	0.80	0.25	0.40

1 Values used in economic analyses presented in this manuscript
2 Includes fertilizer, land rent, overhead

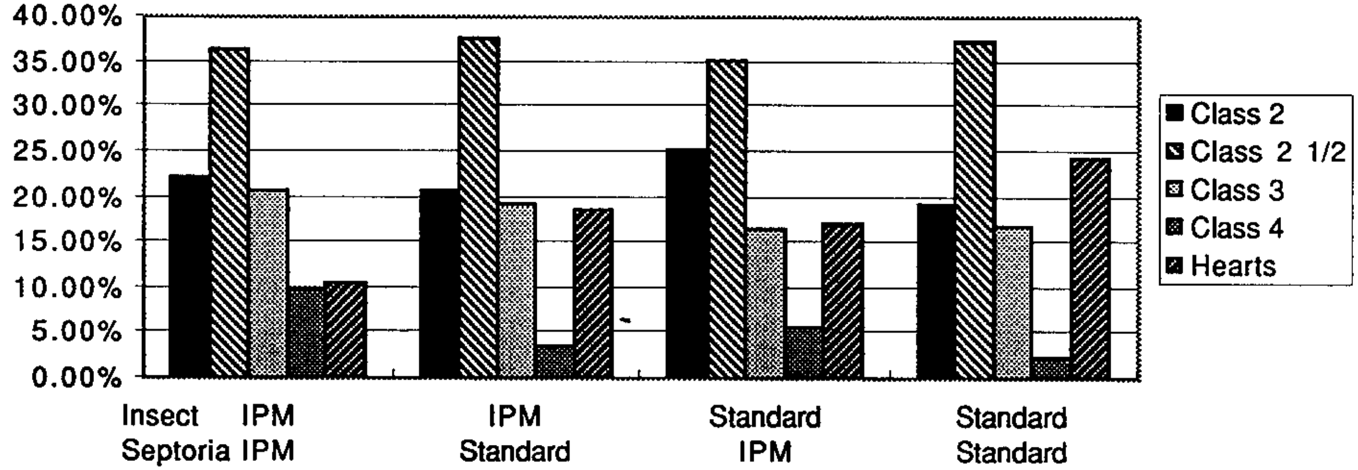

Figure 1. Proportion of cartons in each size class for celery harvested Decemebr 26 and 27 at Ventura commercial fields.

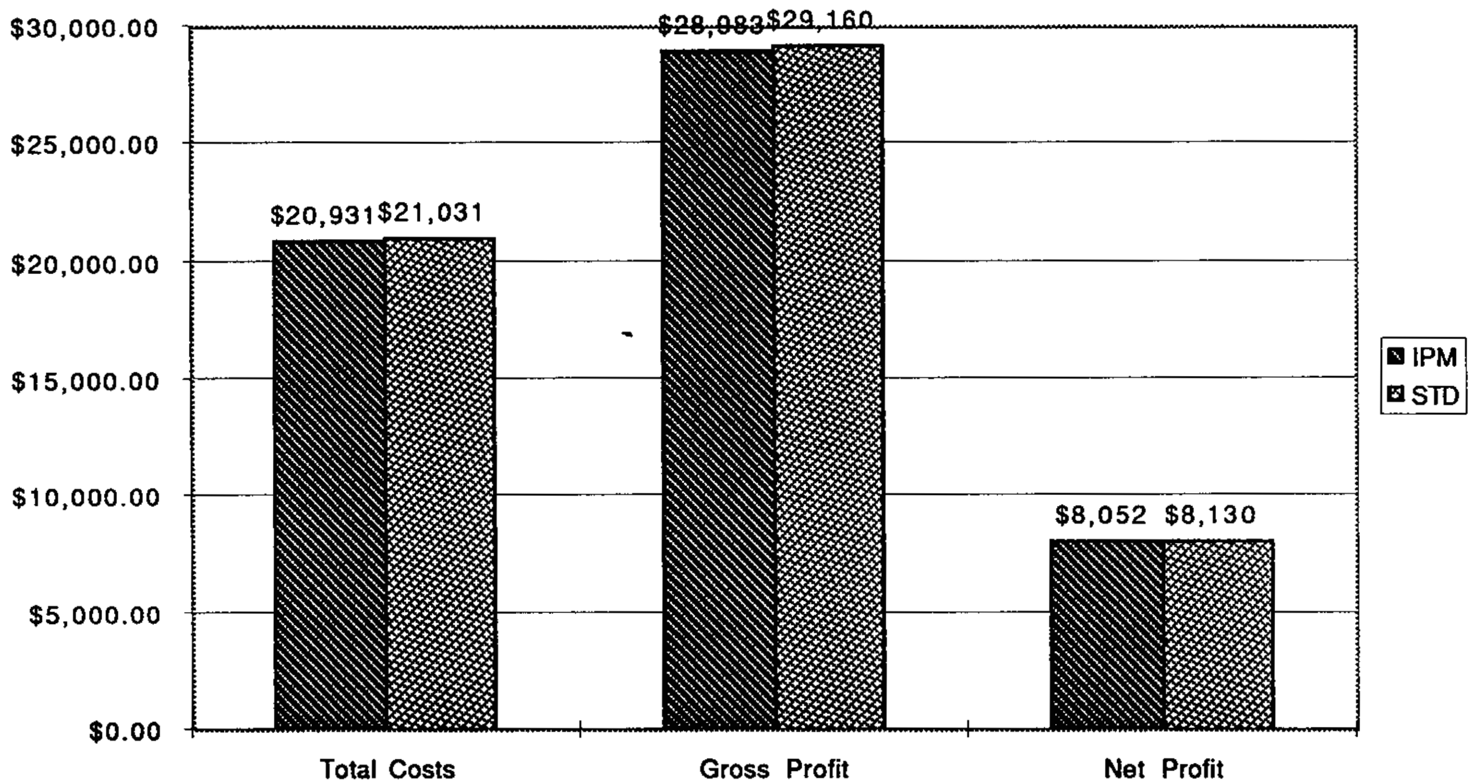

Figure 2. Economic analysis for celery harvest on Decemebr 26 and 27, 1997 at Ventura. Total Costs include all production, harvest and marketing expenses. Gross profits are derived from the Free on Board (F.O.B.) prices for each size class of celery.